

SECTION II. EQUIPMENT AND CHEMICALS

4-6. EXTERNAL TREATMENT EQUIPMENT

External treatment equipment includes water softeners, dealkalizers, degasifiers, demineralizers, and deaerating equipment. Some type of external treatment equipment is generally required for any central plant operating above 15 psig. In selecting external treatment equipment, table 4-3 and the information presented in this section may be used as a guide. This manual does not, however, provide guidance for many water treatment problems. Furthermore, the information presented is of a general nature, and must be supplemented by a qualified water consultant to select the optimum system for a given set of raw water and feedwater conditions. Consult your operating agency commander for further assistance. The common systems used in Army boiler plants are capable of furnishing water to the boilers with a remaining alkalinity, expressed as CaCO_3 , of less than 20 ppm when a hydrogen zeolite or chloride anion exchanger is used. Average hardness should not exceed 2 ppm CaCO_3 when sodium zeolite or hot lime plus hot sodium zeolite is used or 25 ppm when a lime soda softener is used. Figure 4-4 illustrates the effects of these various external treatments on raw water.

a. Sodium Zeolite Softeners. The sodium zeolite process is the most common and simplest system for softening hard water, and is the one normally referred to when the term "zeolite softening" is used. The primary purpose of sodium zeolite softening is the removal of the scale-forming ions of calcium and magnesium and replacement of them with an equivalent amount of sodium ions. It consists of a zeolite tank with attached regeneration control mechanism, a salt storage tank, and a brine solution measuring tank. Raw water under pressure enters the top through the control valve, hits a splash plate, and drops onto the zeolite bed. Layers of graded gravel support the bed. In the zeolite bed, calcium and magnesium ions are replaced with sodium ions. There is an underdrain system beneath the gravel that collects the softened downflow water and discharges backwash water upward during regeneration. Above the zeolite bed, an arrangement of laterals collects the backwash water and sprays the brine solution over the zeolite bed during regeneration. The space above the top of the zeolite bed is called the free-board. Its function is to provide room for expansion of the zeolite bed and to prevent loss of zeolite during backwashing. The bed is compressed during the softening run. Control of the softening and regeneration cycles may be either manual or automatic. In a manual system, a valve nest or a multiport valve is provided to control the regeneration steps. A fully automatic sodium zeolite softener is illustrated in

figure 4-5. In a unit with automatic operation, a meter on the soft water effluent line actuates the control valve after a predetermined quantity of water has been softened. This action takes the softener unit off the line and starts the regeneration cycle. On completion of regeneration, the unit reverts to the softening cycle. The heart of regeneration control, either for automatic or manual operation, is the multiport valve, which opens and closes ports, admitting regenerants and rinse water for the various operations of regeneration. Additional control is provided by wash water and rinse water rate-of-flow controllers. These controllers are either float-operated butterfly valves in sumps or automatic-throttling backwash outlet valves. Brine may be transferred from the brine measuring tank to the zeolite tank either by pump or hydraulic ejector. The disadvantage of the sodium zeolite process is that it does not reduce total solids, alkalinity, and silica. Ion exchange materials may also be degraded or blocked by suspended matter and other impurities present in the incoming water.

b. Hot Process Lime-Soda Softeners. Lime-soda softening is used to precipitate hardness. It also can remove silica, provide deaeration of the boiler makeup water, and provide filtration of suspended matter. It has the advantage of being able to treat large quantities of water in a relatively compact unit. Figure 4-6 illustrates this equipment. The general procedure for this type of softening is to heat the water to 212° F or higher, using live or exhaust steam in a deaerating section. The deaerating section is thoroughly vented at all times to remove gases. High operating temperatures promote maximum treatment efficiency. A mixture of lime (Ca(OH)_2) and soda ash (Na_2CO_3) is added to the hot water to remove both carbonate and noncarbonate hardness. Calcium bicarbonate and magnesium bicarbonate react with lime, producing insoluble calcium carbonate and magnesium hydroxide, respectively. Typical reactions to remove non-carbonate hardness include converting calcium sulfate to calcium carbonate and sodium sulfate and converting magnesium sulfate to insoluble magnesium hydroxide and sodium sulfate. The hardness precipitates as a sludge and settles to the bottom of the tank from which it is periodically removed. The softened water settles to the bottom of the tank, then rises to the tank discharge, and flows to a filter. This process requires one to two hours. The filter removes the remaining precipitate, leaving a clear effluent. The lime-soda softening process does not reduce hardness of a softened water to as low a value as do the ion-exchange softening processes. Hardness can be reduced to approximately 10 to 30 ppm as calcium carbonate, depending upon the temperature of the operation and the alkalinity maintained. Consequently,

Table 4-3. Guide for Selection of External Treatment Equipment

Makeup Requirements	Steam Pressure	Alkalinity	Turbidity	Recommended External Treatment Equipment
GPM	PSIG	PPM-CaCO ₃	PPM	
All	Less than 15	All	Less than 10	Normally internal treatment only.
			Over 10	Filtration plus internal treatment.
Less than 100	15-200	Less than 75	Less than 10	Sodium Zeolite.
			Over 10	Filtration plus sodium zeolite.
		Over 75	Less than 10	1. Sodium zeolite plus hydrogen zeolite (3). 2. Sodium zeolite plus chloride/anion exchange. 3. Hydrogen zeolite (3, 5).
			Over 10	1. Filtration plus sodium zeolite plus hydrogen zeolite. 2. Hydrogen zeolite (3, 5).
	200-650	Less than 35	Less than 10	Sodium zeolite.
			Over 10	Filtration plus sodium zeolite.
		Over 35	Less than 10	1. Sodium zeolite plus hydrogen zeolite (3). 2. Demineralization.
			Over 10	1. Filtration plus sodium zeolite plus hydrogen zeolite. 2. Filtration plus demineralization.
Over 100	15-200	Less than 75	Less than 10	Sodium zeolite.
			Over 10	1. Filtration plus sodium zeolite. 2. Hot lime soda.
		Over 75	Less than 10	Sodium zeolite plus hydrogen zeolite (3).
			Over 10	1. Filtration plus sodium zeolite plus hydrogen zeolite (3). 2. Filtration plus demineralization.
	200-650	All	Less than 10	1. Sodium zeolite plus hydrogen zeolite (3). 2. Demineralization.
			Over 10	1. Filtration plus sodium zeolite plus hydrogen zeolite (3). 2. Filtration plus demineralization. 3. Hot-lime hot-sodium zeolite. Above psig.
All	Over 650 (Normally Superheated)	All	Less than 10	Demineralization.
			10-400	Filtration plus demineralization.
			Over 400	1. Filtration plus demineralization. 2. Reverse osmosis. 3. Electrodialysis.

NOTES

1. The above chart provides general guidelines only. Final choice of treatment system must be based upon complete raw water analysis, feedwater requirements, and overall economics, including both external and internal treatment and blowdown. External treatment may be desirable to reach recommended levels of TDS without exceeding other parameter limits for causticity, silica, or suspended solids.
2. Separate deaeration is required to all boilers over 15 psig pressure, except where lime-soda softeners are designed to provide adequate deaeration as well as softening.
3. Degasification is required after hydrogen zeolite treatment.
4. Filtration process may require clarification and aeration.
5. Flows less than 10 gpm or very low sulfate plus chloride content.

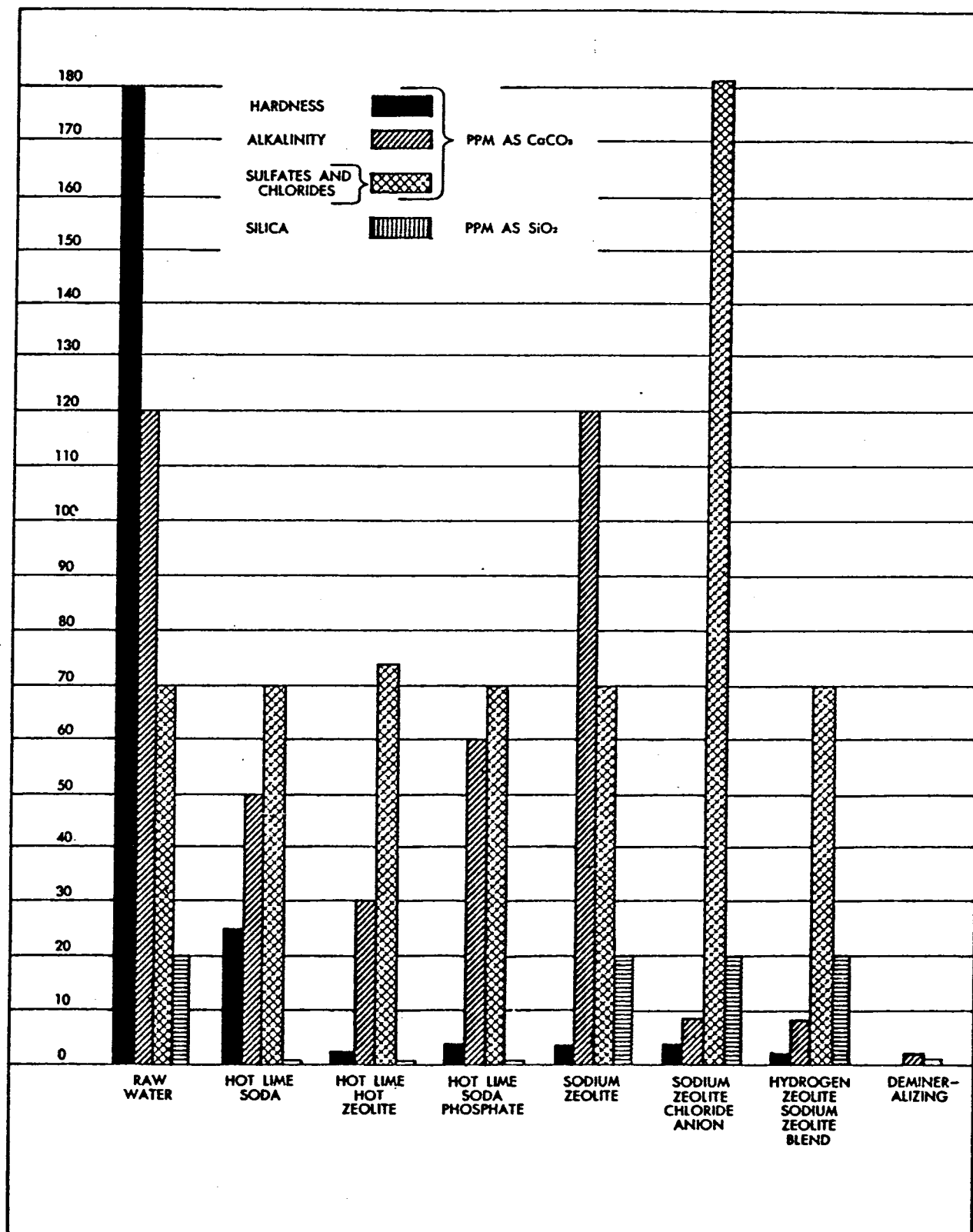


FIGURE 4-4. EFFECTS OF TREATMENT ON RAW WATER

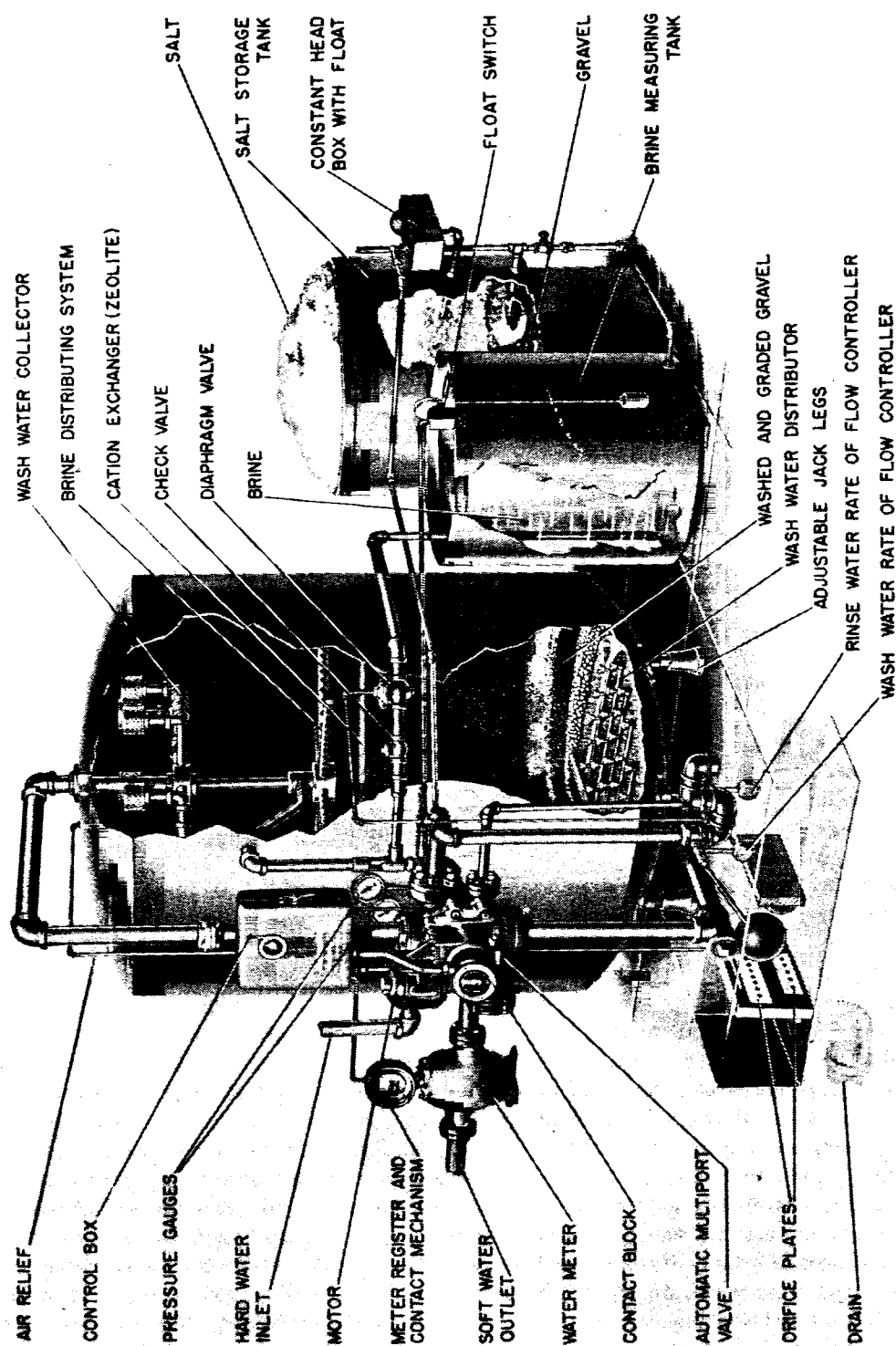


FIGURE 4-5. SODIUM ZEOLITE SOFTENER

where lime-soda softened water is used for boiler makeup water, internal chemical treatment requirements are higher than if ion-exchange softened water is used. Because hardness can be reduced to no lower than 10 to 30 ppm, there is little advantage to this process where raw water hardness is already less than 50 ppm. On waters of high non-carbonate hardness, there will be no decrease in solids content, and under some conditions there may actually be an increase. Finally, control of the process is more difficult than control of ion-exchange softeners, and more frequent testing of the effluent is required. Because of these limitations, lime-soda softening is rarely used alone in modern Army boiler plants.

c. Hot-Lime Hot-Sodium Zeolite Softeners. Combination hot-lime hot-sodium zeolite softening is used for treatment of makeup supply to boilers operating above 400 psig when the makeup is high in calcium and magnesium bicarbonate hardness. The equipment used in this process is a combination of hot process lime-soda and sodium zeolite softening with minor modifications. Figure 4-7 shows a flow diagram of a typical hot-lime hot-sodium zeolite system. The process involves the softening of raw water with lime. After settling and filtering have occurred, the hot filtered effluent is passed through a sodium zeolite water softener. The chief advantage of this method of treatment is that it almost completely removes hardness and reduces alkalinity. In plants operating at lower boiler pressures with a reasonable quantity of return condensate however, the installation of a hot-lime hot-ion exchange system represents a considerable expense that may not be economically justified. The limitations of the system must be thoroughly studied and evaluated to ensure that it is practical and economic for a given set of plant requirements.

d. Hydrogen Zeolite Softeners. The hydrogen zeolite process reduces hardness in a manner similar to that of the sodium zeolite process. It differs however, in that acid is used instead of salt for regeneration and hydrogen instead of sodium is exchanged for the cations calcium and magnesium. The salts of these cations are converted into their corresponding acids. The carbonic acid resulting from the hydrogen exchange in carbonates and bicarbonates breaks down into carbon dioxide gas which can be liberated by aeration. Thus, this process not only softens the water but also removes alkalinity, and can result in a marked decrease in solids content. It is primarily used in boiler feedwater conditioning where the makeup water is low in hardness and high in bicarbonate alkalinity. It is necessary to neutralize the acid effluent from the hydrogen zeolite unit. This is done in one of two ways: blending the hydrogen zeolite effluent with the effluent of a sodium zeolite unit operating in parallel (figure 4-8) or adding an alkali such as caustic soda (figure 4-9). The correct proportions of water to pass through the two zeolite systems depend upon

the following factors: the alkalinity of the raw water; the free acid contained in the hydrogen zeolite effluent (which in turn depends upon the sulfate, nitrate, and chloride content of the raw water); and the alkalinity desired in the final mixed effluent. Adjustments can easily be made for correct proportions of effluents from the hydrogen and sodium zeolite units. In the absence of a sodium zeolite blend, the use of an alkali is economical when either the quantity of the water to be treated or the sum of the sulfates and chlorides present is so small that only negligible quantities of alkali are required.

(1) When the hydrogen zeolite becomes exhausted, it is backwashed with makeup water, and regenerated with a dilute solution of acid. This restores hydrogen to the zeolite and simultaneously removes the calcium, magnesium, and sodium which were taken up by the zeolite during the softening run. After the calcium, magnesium, sodium, and any excess acid are rinsed out of the softener, the unit is restored to service. In rinsing, free mineral acidity (FMA) is used as an indication of the end of the rinse cycle. FMA will vary according to characteristics of the raw water supply, and the amount of rinsing required will vary accordingly.

(2) The neutralized effluent of the hydrogen zeolite unit is pumped to a closed degasifier (figure 4-10) to scrub out carbon dioxide. This is done by forcing air into the bottom of the degasifier. The air rises past the falling water and absorbs the dissolved carbon dioxide. Water leaving the degasifier is oxygen saturated and must be deaerated before going to the boilers. General precautions for periodic inspections and care of hydrogen zeolite units are the same as for sodium zeolite units. Particular care must be given to the rate of flow and exhaustion points of acid-regenerated units, since excessive flow rates and overrunning of the unit will destroy the softening material. Before a definite recommendation for this type of equipment can be made, it is necessary to make a thorough study of its economics and practicality. In general, such a study will show that the hydrogen zeolite system is more expensive and unwarranted for Army central boiler plants.

e. Chloride Anion Exchanger/Dealkalizer. The chloride anion exchange process reduces alkalinity in makeup water without acid treatment or hydrogen zeolite, and is often used in series with a sodium zeolite unit. It is regenerated with salt and a small percentage of caustic soda. While not as economical or efficient as acid treatment or hydrogen zeolite, it has the advantage of obtaining similar reductions in alkalinity without the necessity of handling acids. Chloride anion exchanger units are used most frequently in relative small boiler plants. The principle involved is the exchange of bicarbonate ions in the makeup water for the chloride of a resinous chloride material. The whole process is similar to the cation exchange in the sodium

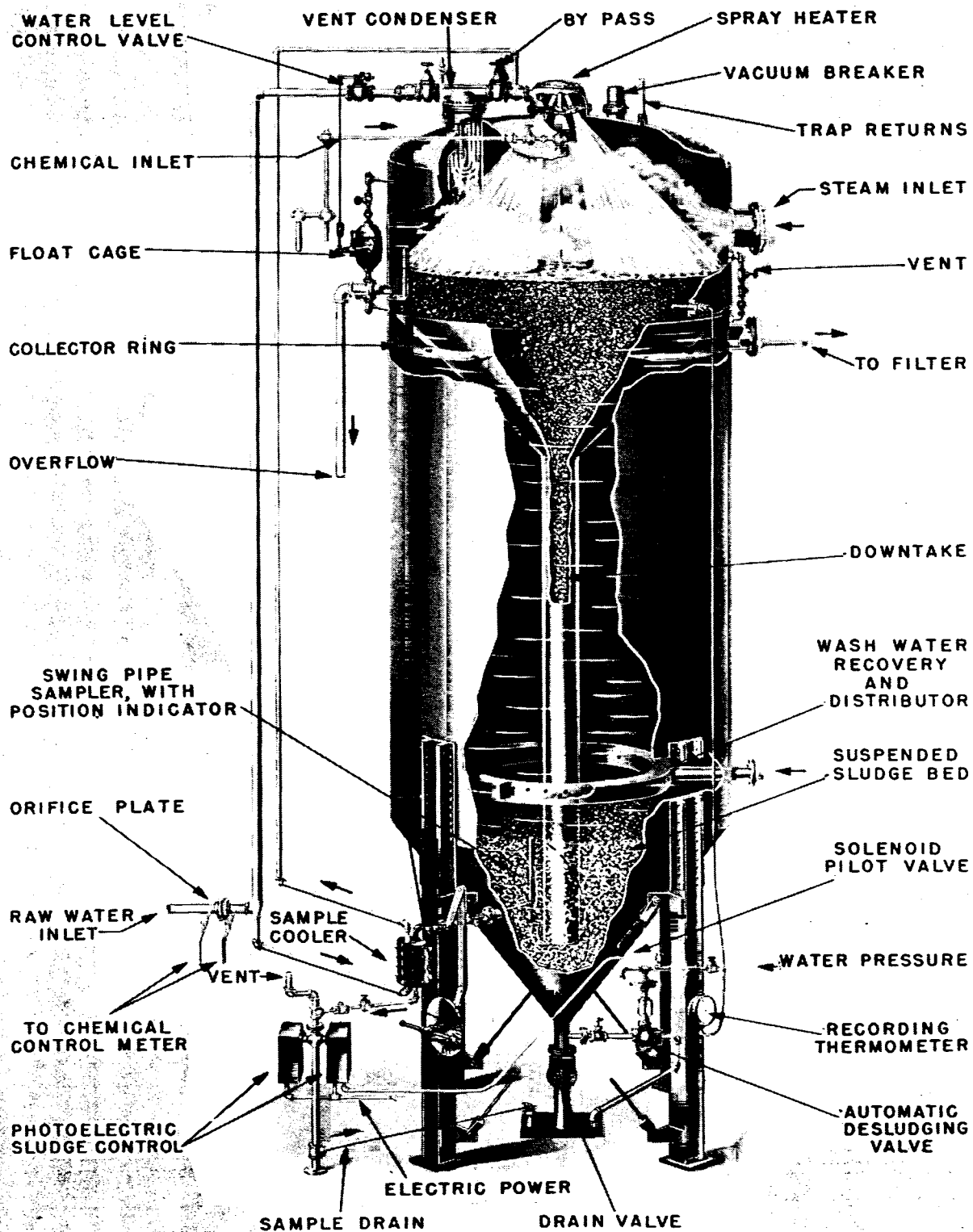


FIGURE 4-6. HOT PROCESS LIME SODA SOFTENER

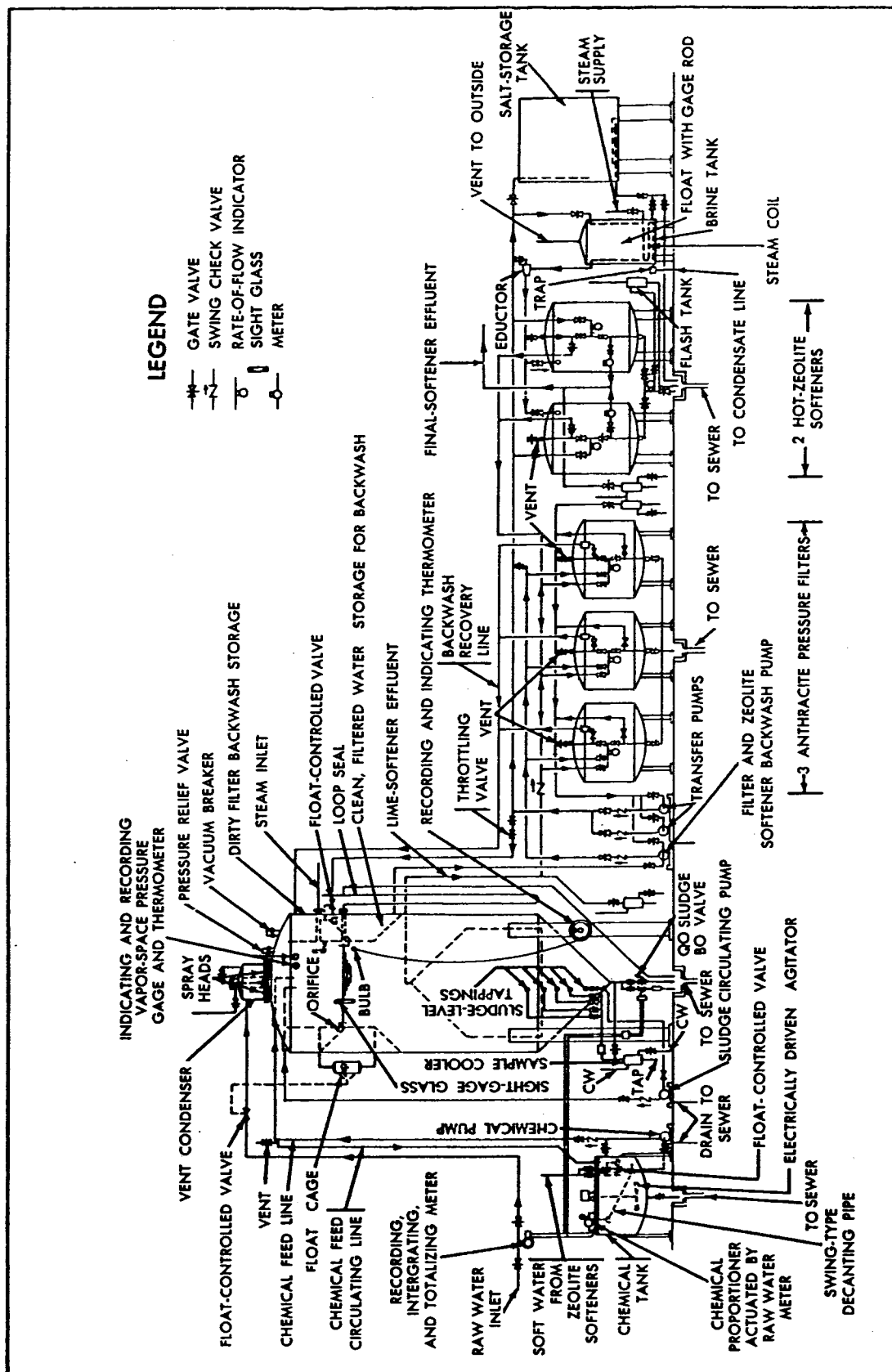


FIGURE 4-7. HOT-LIME HOT-SODIUM ZEOLITE SOFTENER

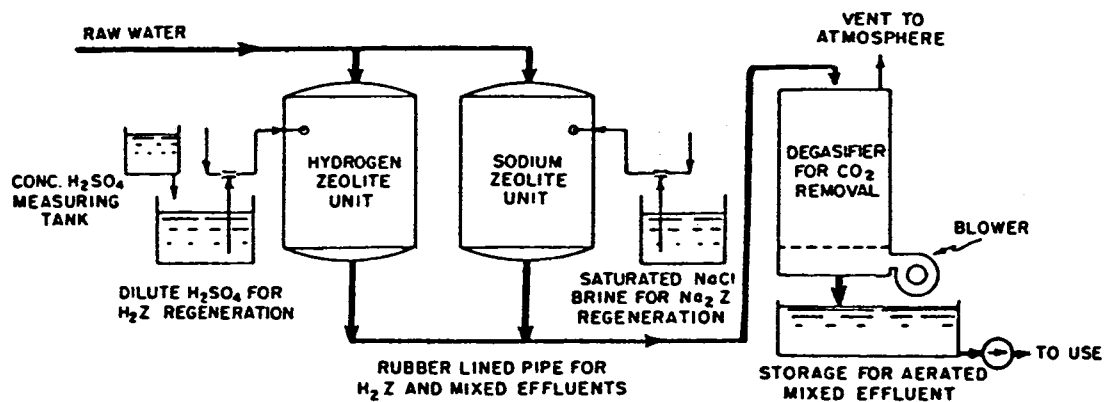


FIGURE 4-8. HYDROGEN AND SODIUM ZEOLITE SOFTENERS OPERATING IN PARALLEL

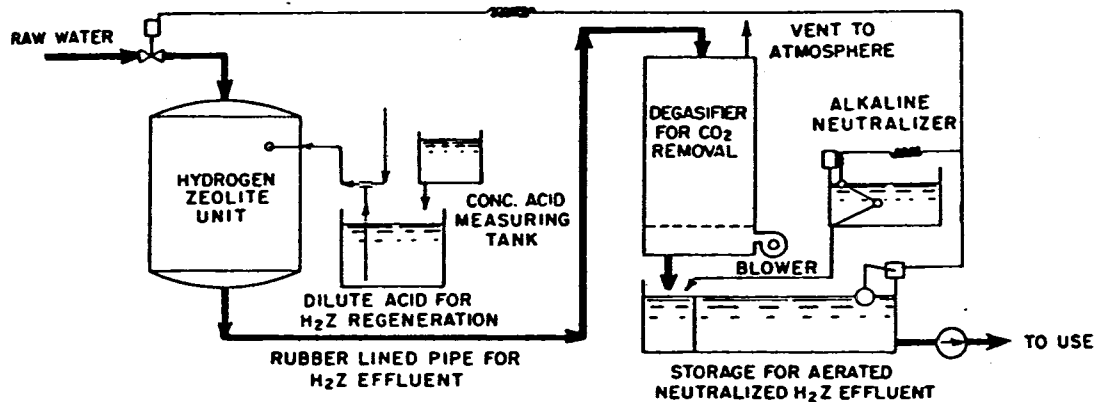


FIGURE 4-9. HYDROGEN ZEOLITE WITH ALKALINE NEUTRALIZATION

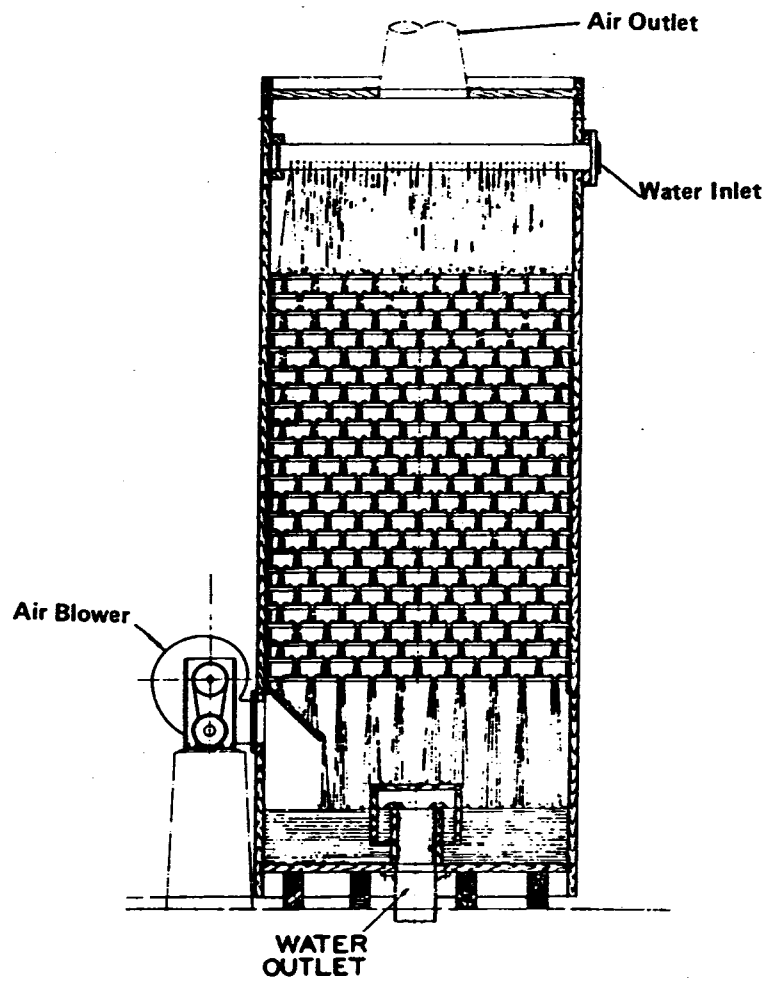


FIGURE 4-10. DEGASIFIER/DECARBONATING TOWER

cycle, except that anions are exchanged instead of cations. The equipment involved, method of operation, and regeneration are the same as for the zeolite softener. This process should not be used on dirty makeup water, because dirt cannot be removed easily by backwashing. When this method is combined in series with a sodium zeolite unit and degasifier, both hardness and alkalinity are reduced. Figure 4-11 shows a typical system. The main disadvantages of the process are that it does not reduce silica, and that salt is added, thereby increasing the conductivity which may result in increased blowdown. Demineralization is frequently a more economical approach for treating high impurity water.

f. Demineralizers. Unlike the zeolite softeners which remove only cations, demineralizers remove both cations and anions. These ions are replaced by hydrogen and hydroxide ions which combine to form water. The resulting effluent is equal to or better than distilled water. Demineralizers, which are also commonly called "deionizers," are generally used with high or medium pressure boilers or in plants requiring high-purity water.

(1) Demineralization is most often accomplished by first passing the water through a column of cation exchange resin. As water moves through the resin, it leaves its cations on the resin while it picks up hydrogen ions. Next, the water passes through a column of anion exchange resin. Here, the water leaves its anions on the resin and picks up hydroxide ions. The hydroxide ions then combine with the hydrogen ions to form essentially pure water. Another arrangement which is sometimes used is mixed bed demineralization. This combines the cation and anion resins in a uniform mixture in one column, resulting in an effective infinite series of cation-anion exchange systems. Figure 4-12 illustrates a mixed bed demineralizer unit and its regeneration cycle. There are many variations of these arrangements. Either strong or weak cation or anion resins can be used, and the equipment can be arranged in two-bed, three-bed, or mixed-bed configurations. Strong cation resin has the ability to remove sodium whereas weak cation resin does not. Strong anion resin has the added ability over weak anion resin to remove carbon dioxide, carbonate, bicarbonate, and silica. In some cases, degasifiers are also added to the system. When the acids generated in the cation column react with alkalinity in the raw water, carbon dioxide can form. This can be removed by ion exchange or by degasification, depending on the system.

(2) After an ion-exchange resin has exhausted the amount of ions it has available for exchange, it must be regenerated. The regeneration process starts by loosening the bed by reverse flow of water through the column. The resin is then regenerated with a downward flow of regenerants. An acid solution is used for a cation resin

and a caustic solution for an anion resin. The regenerant chemical is finally displaced by a slow flow of water through the resin followed by a rapid rinse to remove all traces of the regenerant chemical. Demineralization produces better makeup water than any of the methods discussed previously. It is an extremely versatile process, and the resins can be adjusted to suit almost any combination of raw water quality and makeup chemistry requirements. Choice of demineralization over other systems is more a function of makeup water requirements than raw water quality. Its advantages include reduced boiler blowdown and resulting reduced makeup requirements, and a big assist in the production of high quality steam. Its main drawback is its higher equipment and operating cost. It is usually difficult to justify a demineralization system unless the plant operates in the range of 600 psig or above, a pressure at which few Army boiler plants operate.

g. Electrodialysis and Reverse Osmosis. The softeners and demineralizers discussed previously are the normal choices for common water sources, including city systems, rivers, streams, and wells. Industrial plants, and in some cases Army boiler plants, may also be required to operate on less pure water such as brackish or high turbidity sources from a deep well or estuary with several thousand parts per million or greater solids. Various membrane and distillation techniques are available to handle these special situations. Electrodialysis and reverse osmosis are two of these having the longest development history. Electrodialysis operates by passing the water between sets of parallel membranes carrying an electric field. The charged field causes the cations to migrate toward the negatively charged electrode, and the anions in the opposite direction. The membranes used are selectively permeable to allow the passage of ions from the "pure" stream to the "brine" stream. Reverse osmosis systems operate on the principle that when two salt water solutions of different concentrations are separated by a semipermeable membrane, water will be transported from the dilute to the more concentrated side. When pressure is applied to the concentrated side, the water will flow in the reverse direction. The process is thus one of concentration, resulting in one stream more concentrated in salt than the original feed, and one that is purer. These treatments, and other similarly exotic systems, are generally expensive, and have high operation costs. They may be applied, however, either by themselves or in combination with one of the other systems discussed to meet specialized treatment requirements. Assistance should be obtained from the operating agency commander.

h. Deaerating Heaters and Deaerators. Deaerating heaters and deaerators are used in steam boiler plants to remove oxygen and other dissolved non-condensable gases from the boiler feedwater and also to minimize the amount of internal treatment required for oxygen control. This

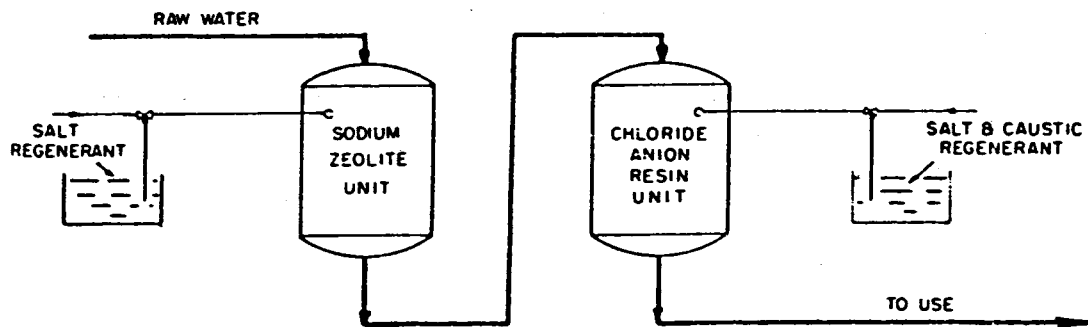
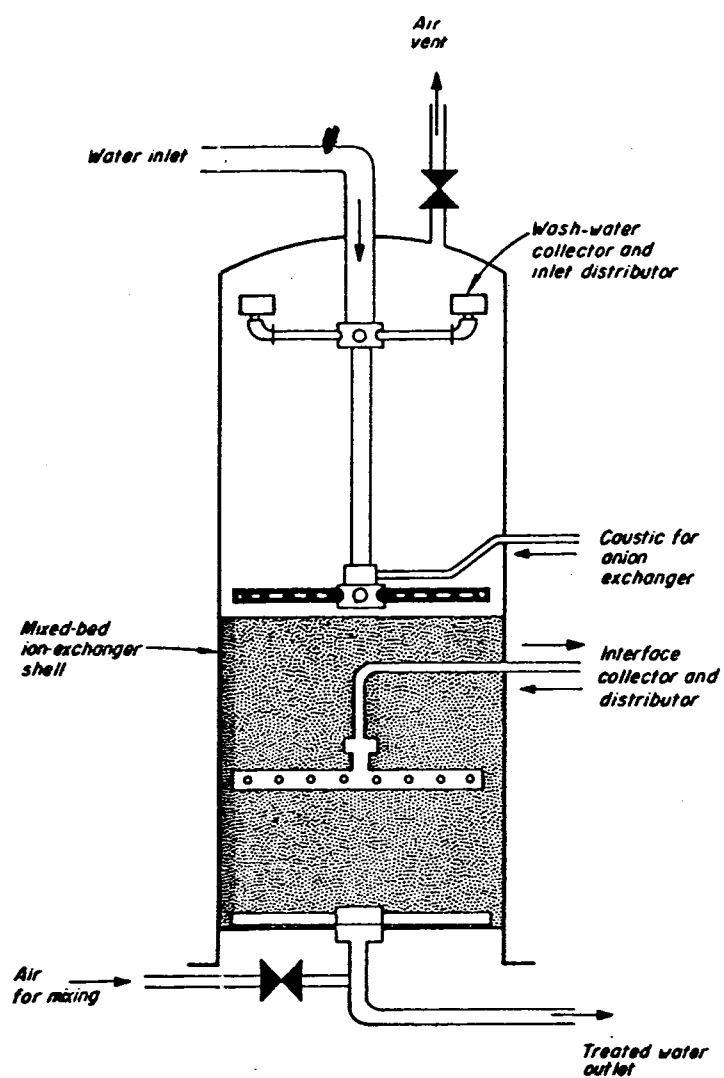
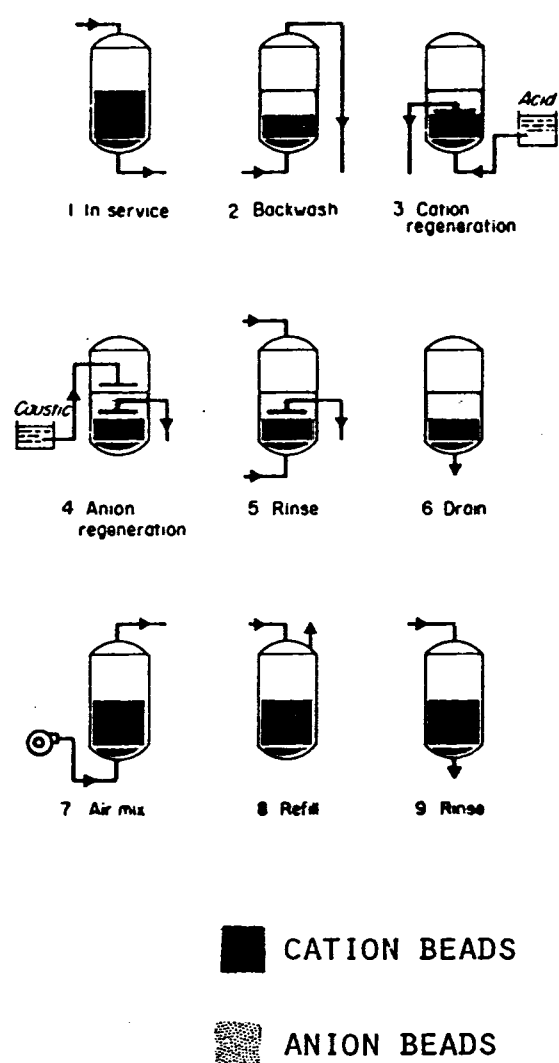


FIGURE 4-11. SODIUM ZEOLITE-CHLORIDE
ION EXCHANGE SYSTEM



A. MIXED BED DEMINERALIZER



B. REGENERATION CYCLE

FIGURE 4-12. DEMINERALIZER

deaeration is necessary to minimize corrosion in the boiler and steam distribution system. The other major function of the deaerating heater and deaerator is to heat the boiler feedwater to a temperature at which it can be fed to the boiler without causing thermal shock. Boiler plant efficiency can be improved if turbine exhaust or other waste steam is available for heating the feedwater. Deaerating heaters and deaerators can serve to receive and store condensate. All steam plants operating above 15 psig with an installed capacity of more than 100 horsepower or 3,500 pounds per hour should be equipped with a deaerating heater, deaerator, or a hot lime-soda softener which includes a deaerating section. Hot water plants do not normally require deaerating equipment. Plants not equipped with some type of deaerating equipment will usually have a feedwater heater. Feedwater heaters are discussed in paragraph 2-36. Deaerators operate by heating the water to the boiling temperature. Since the solubility of any gas in water is zero at or above the boiling point, oxygen and other noncondensable gases come out of solution and can be vented to atmosphere. The maintenance of proper temperature is critical and provisions must be made to supply live steam to the deaerating section if sufficient exhaust steam is not available. See paragraphs 4-16c(1) and (2) which further discuss deaerator operation.

(1) **Types of Deaeration Equipment.** The three types of deaeration equipment are deaerating heaters, tray deaerators and spray deaerators. Newer boiler plants are equipped with tray or spray type deaerators because of their ability to reduce dissolved oxygen levels to less than seven parts per billion compared with approximately forty parts per billion for a deaerating heater. The deaerating heater is an open vented tank in which the feedwater is heated to above 212° F by a steam coil in the bottom of the tank. In the tray deaerator, shown in figure 4-13, water enters at the top and cascades down through a series of trays or baffles while steam enters at the side and passes upward through the falling water droplets, heating the water. The water droplets expose a large surface area to the steam, aiding the heating process. The dissolved gases are expelled from the water through the deaerator vent. The spray deaerator atomizes the incoming water into fine droplets and mixes this spray with steam for heating and deaeration. The spray deaerator is shown in figure 4-14.

(2) **Typical Deaerator Installations.** Deaerators are installed on elevated structures above the boiler feed pump suction to provide sufficient NPSH and prevent flashing at the pump inlet under the feed temperature conditions. With a feedwater temperature of 214° F and a back pressure on the deaerator of approximately 0.5 psig, the hydrostatic head on the feed pumps should be approximately seven feet. If the boiler feedwater temperature is held above 214° F, the hydrostatic head must be increased proportionately.

The three common types of deaerator installations are described below.

(a) **Type I.** Type I (figure 4-15), is the most common. All returns are pumped to the surge tank where makeup is added as needed and the water controlled by the load demand, is allowed to flow by gravity to the deaerator. Storage at the deaerator for this type of installation is small (generally not over a 3-minute plant supply), because the primary reserve is maintained in the surge tank which also takes care of sudden surges of condensate. Feedwater enters and leaves this type of deaerator uniformly at a rate equal to the feedwater requirements of the boilers. The makeup level in the surge tank should be as low as is consistent with safe operation (minimum of 10-minute supply — total space for 30-minute supply) to permit ample storage space for sudden surges of return condensate.

(b) **Type II.** In Type II deaerator installations (figure 4-16), all condensate returns are pumped directly to the heater. Storage space is maintained after the deaerator compartment. Makeup is added as required directly through the deaerator, also maintaining as low a makeup level as is safe (minimum 10-minute supply — total space for 30-minute supply) to permit storage space for sudden surges of condensate. This type of installation can impose high intermittent loads on the deaerator as area condensate pumps start and stop, and requires a deaerator of greater capacity to handle the same average load as Type I. As pumps normally operate approximately 25 percent of the time, a load three to four times the average load is imposed when all of the condensate return pumps happen to be operating at the same time. Therefore, feedwater enters this type of deaerator intermittently at a rate of three to four times the rate of feed to the boilers.

(c) **Type III.** Type III deaerator installations (figure 4-17) are an adaptation of Type I installations. These installations use a transfer pump to pump water from the surge tank to the deaerator, because sufficient head room is not available for gravity flow. Most transfer pumps are steam driven, providing an even flow of water to the deaerator at a rate equivalent to the output of the boilers. Where electric-driven transfer pumps are used, it is essential that they be of the continuous operating type, pumping feedwater to the deaerator by action of float-operated water level control. If low and high water floats are used to start and stop the pump, intermittent loads equivalent to the capacity of the transfer pump are imposed on the deaerator; unless the deaerator is sized accordingly, overloading will result.

(3) **Deaerator Auxiliary Equipment.** Deaerators are equipped with some or all of the following auxiliary equipment.

(a) **Surge Tanks.** Steel surge tanks, installed ahead of the feedwater heaters, should be provided for the storage

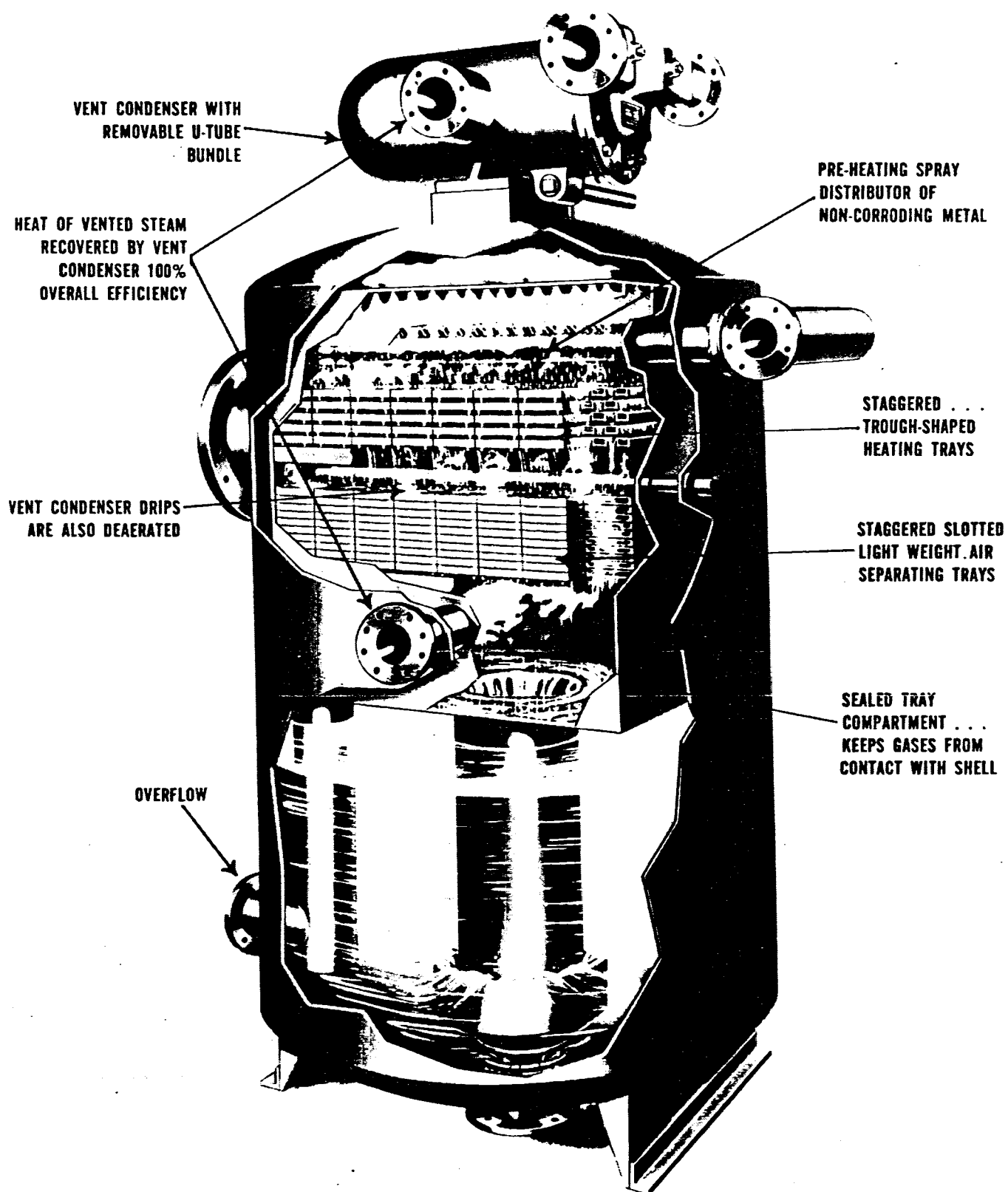


FIGURE 4-13. TRAY DEAERATOR

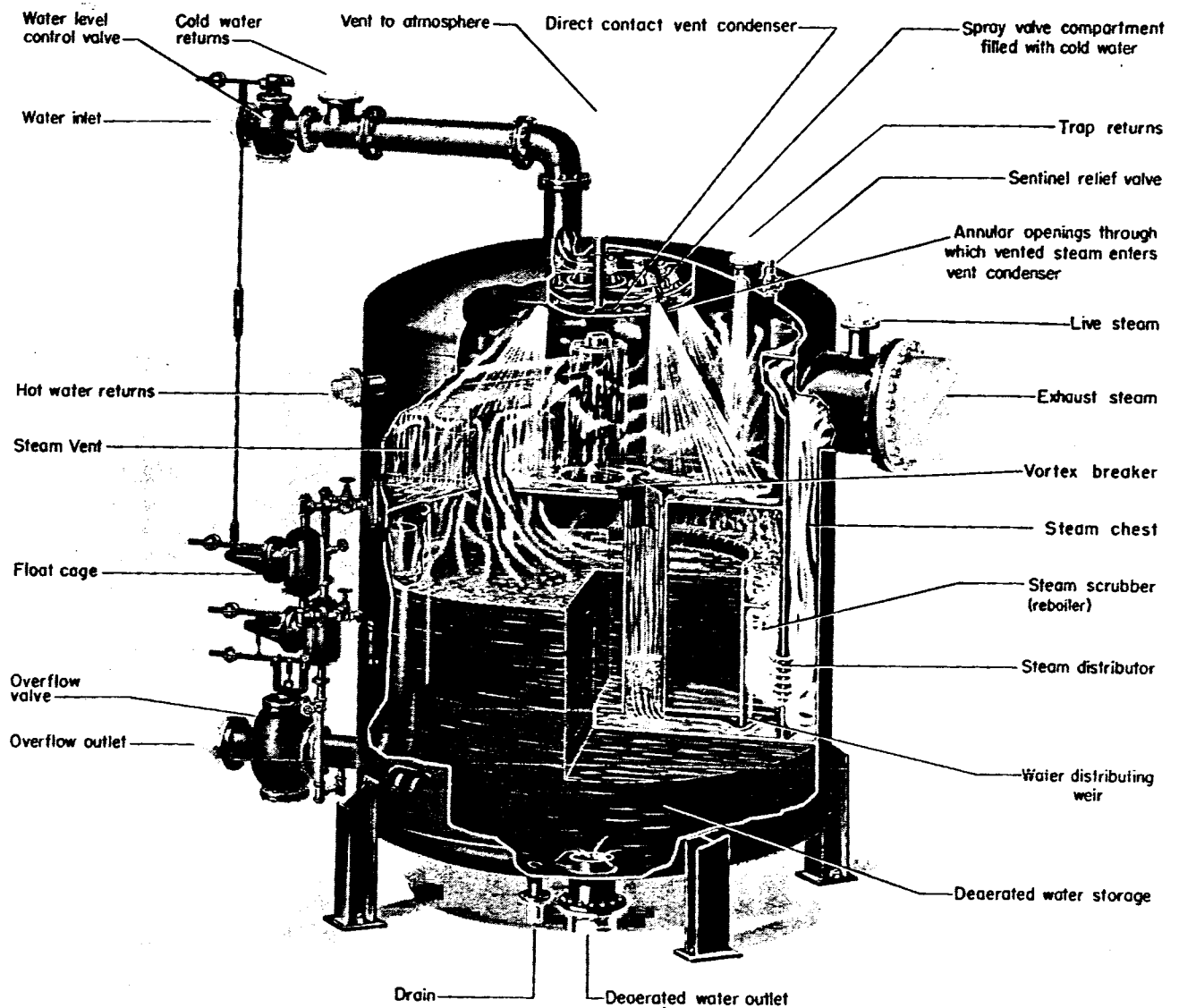


FIGURE 4-14. SPRAY DEAERATOR

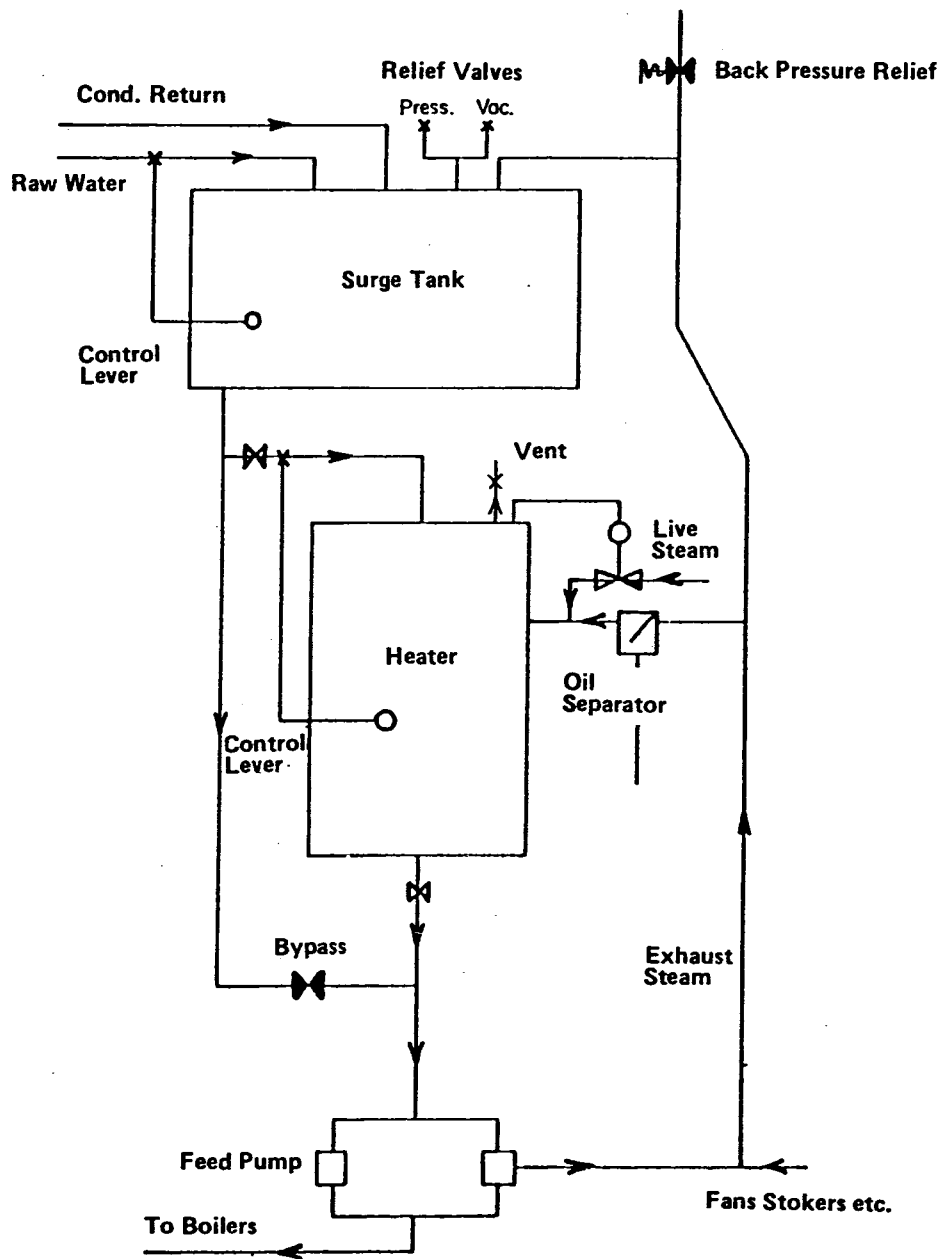


FIGURE 4-15. TYPE I DEAERATOR INSTALLATION

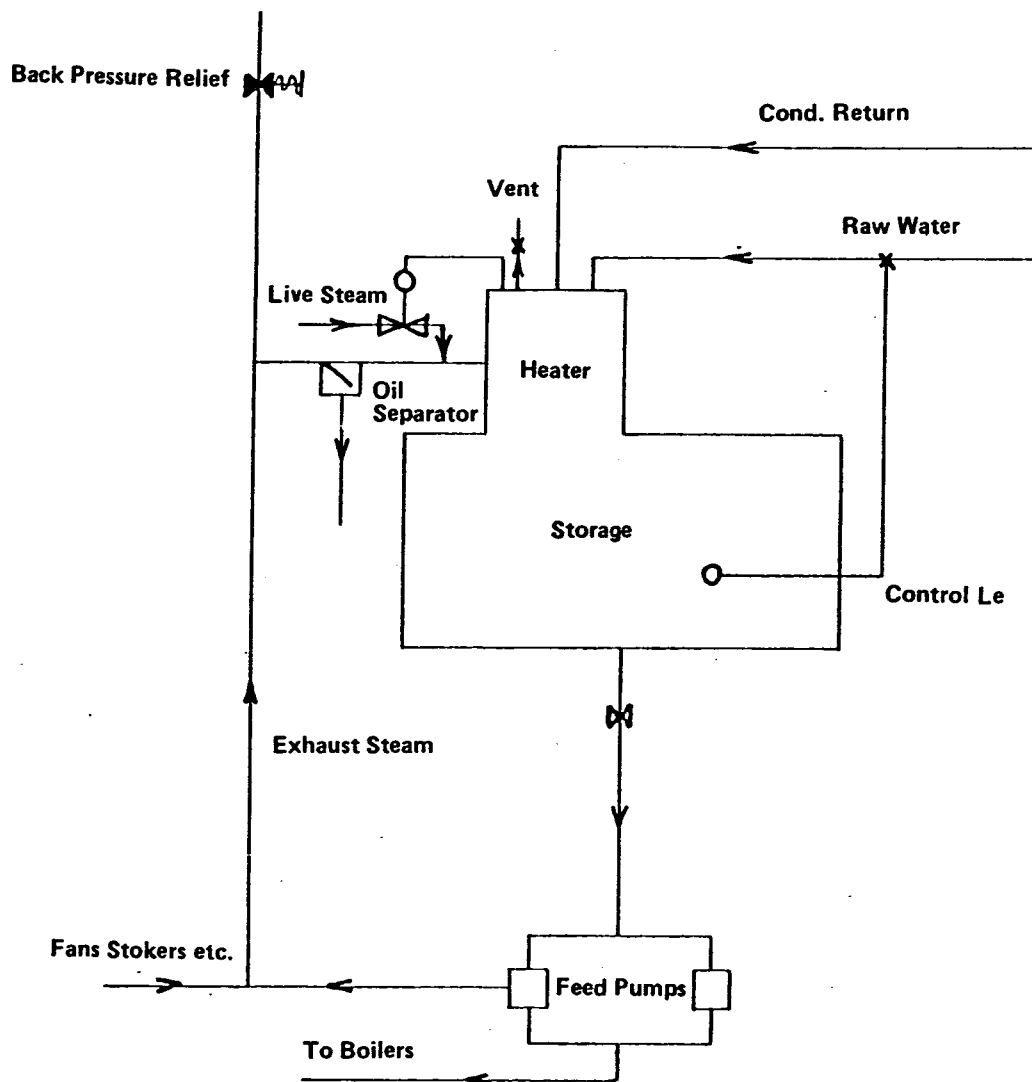


FIGURE 4-16. TYPE II DEAERATOR INSTALLATION

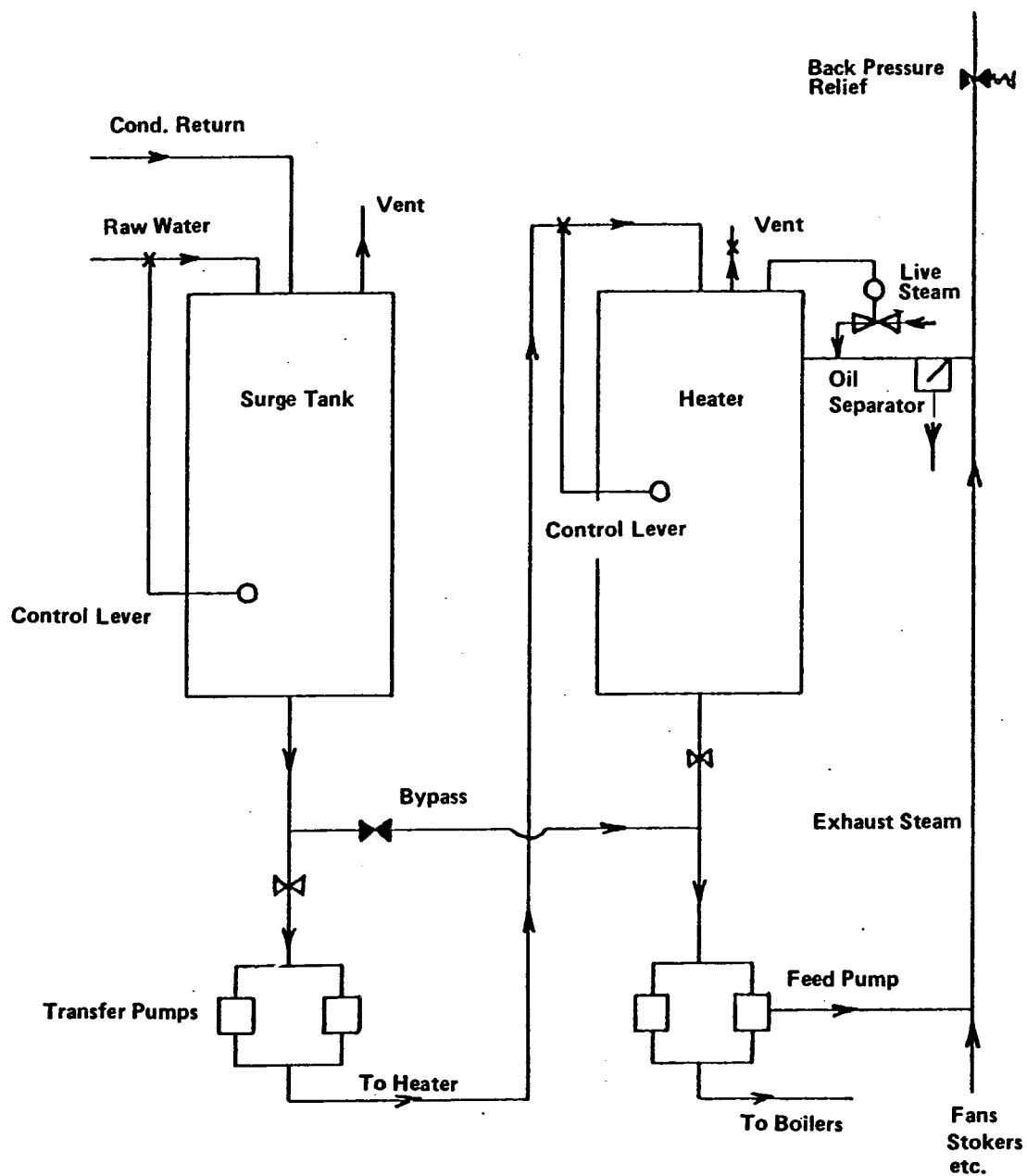


FIGURE 4-17. TYPE III DEAERATOR INSTALLATION

of condensate where the boiler load is primarily for space heating, or where large quantities of condensate are returned by the condensate pumps. Where steam-driven auxiliaries are used in the boiler plant, surge tanks should provide a minimum of 10 minutes storage of makeup water plus 20 minutes storage of condensate, based upon connected load.

(b) Vent Condenser. Deaerators are generally equipped with a vent condenser. Its purpose is to condense the vented vapors and to preheat the water before it enters the deaerating chamber, thus increasing the efficiency of the deaerator. A vent condenser is a tube-type heater mounted on top of the deaerating heater. It condenses most of the vented steam, leaving a higher percentage of oxygen to escape through the vent. The resulting condensate is returned to the deaerating section. The heat recovery secured through the use of a vent condenser permits a larger amount of steam to be vented from the deaerating section without loss of heat.

(c) Deaerator Bypass. Deaerators should be provided with a valved bypass to permit operation of the boilers when the deaerator is being serviced.

(d) Instruments. Every deaerator must be equipped with a direct reading thermometer and pressure gage properly located and accessible for reading. Deaerator operation may also be checked continuously using a temperature and pressure recording instrument installed on the deaerator. The thermometer bulbs should be installed in the water space of the heater approximately four inches below the lowest water level. The pressure elements should be connected into the steam space. A makeup flow meter should be installed in the makeup water line to the heater and a condensate flow meter(s) should also be installed.

(e) Accessories. The use of a highly efficient oil separator is of primary importance if the exhaust steam from equipment in the steam plant contains oil. Sources of oil may be reciprocating pumps, engines, or compressors. Some deaerating heaters are equipped with oil separators, while they are offered as optional equipment on others.

4-7. INTERNAL TREATMENT

The following chemicals and equipment are used to control impurities inside a boiler or distribution system.

a. Maintenance of High pH.

(1) Caustic Soda. Caustic soda (NaOH) is used to increase the pH of feedwater. It provides alkalinity in the form of free hydroxide ions (OH⁻) to neutralize acidity of the boiler water. The proper pH provides the proper conditions for the precipitation of desirable sludges. Phosphate precipitates of calcium and magnesium formed when the pH of the water is less than 10.5 tend to be sticky, whereas if the alkalinity is higher the precipitates

are in the form of a soft, finely divided sludge which can be easily removed by blowdown. Causticity of boiler water also raises the solubility of silica, helping to prevent the formation of silica deposits, and protects the boiler against corrosion by neutralizing the acids.

(2) Soda Ash. Use of soda ash (Na₂CO₃) is not authorized for boilers because it breaks down when heated to form hydroxide ions and carbon dioxide. It may be used however, when caustic soda is not available and alkalinity adjustment is necessary.

(b) Phosphate Chemistry. Phosphate in boiler water at the proper alkalinity (pH greater than 10.5) combines preferentially with calcium to precipitate a calcium phosphate, primarily tricalcium phosphate. Since tricalcium phosphate is insoluble in water, it is retained in suspension as a finely divided and fluid sludge which is easily removed by blowdown. One of many possible reactions can be represented as follows:



While possessing many advantages when properly employed, phosphate internal treatment also has the disadvantage of increasing the tendency of boiler water carryover. This is due to the suspended calcium phosphate particles which tend to stabilize boiler water foam. Any of the sodium phosphate salts listed in Table 4-4 may be used. They all release phosphate ions in hot boiler water, which will react with calcium. Various factors must be considered before determining which of the phosphates listed in the table is best for a given plant.

(1) Types of Sodium Phosphates. The two basic groups of sodium phosphates are "orthophosphates" and "molecularly dehydrated polyphosphates." The orthophosphates react readily with calcium to form a precipitate. Orthophosphates must be fed directly to the boiler to avoid scale and plugging of the feedwater line. The dehydrated polyphosphates will not react with calcium until the molecule picks up water and is rehydrated. This is a delayed reaction and in most cases it is possible to feed polyphosphates into the boiler feed pump suction or the feed line without the reaction occurring until the water is in the boiler. It is safest, however, to feed any phosphate directly into the boiler. Under no circumstances should any phosphate be injected ahead of or into a deaerating heater.

(2) Cost. The relative cost of phosphates may be evaluated on the basis of cost per pound of phosphorous pentoxide (P₂O₅). Column 4 of table 4-4, multiplied by cost per pound of the phosphate chemical, gives the cost per pound of P₂O₅ in that phosphate chemical. Hexameta-phosphate is the most commonly used polyphosphate.

(3) Alkalinity. The alkalinity of the phosphate in boiler water must be considered in phosphate selection. Alkalinity is controlled with caustic soda which is inexpensive

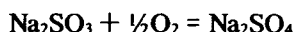
Table 4-4. Common Sodium Phosphates

Name of Phosphate	Symbol	pH*	Percent P_2O_5 Content	Pounds Chemical Per Pound P_2O_5
	(1)	(2)	(3)	(4)
ORTHOPHOSPHATES				
Monosodium phosphate:				
Anhydrous	NaH_2PO_4	4.6	59	1.70
Monohydrate	$NaH_2PO_4 \cdot H_2O$	4.6	52	1.92
Disodium phosphate:				
Crystalline	$Na_2HPO_4 \cdot 2H_2O$	9	39	2.57
Anhydrous	Na_2HPO_4	8.8	48	2.08
Trisodium phosphate:				
Crystalline	$Na_3PO_4 \cdot 12H_2O$	11.8	18.5	5.40
Monohydrate	$Na_3PO_4 \cdot H_2O$	12	39	2.57
MOLECULARLY DEHYDRATED POLYPHOSPHATES				
Hexametaphosphate	$1.1 Na_2O : 1 P_2O_5$	6.7	67.5	1.48
Tetraphosphate	$1.37 Na_2O : 1 P_2O_5$	8.5	62.5	1.60
Septaphosphate	$1.2 Na_2O : 1 P_2O_5$	7.2	63.5	1.57
Sodium Tripolyphosphate	$Na_5P_3O_{10}$	9.5	57.8	1.73
Tetrasodium Pyrophosphate	$Na_4P_2O_7$	10.2	53	1.89

* One percent solution

compared with sodium phosphate. One of the reasons for the common use of hexametaphosphate is that it is almost neutral and therefore simplifies boiler treatment by not affecting alkalinity.

c. Oxygen Control. Although oxygen can be reduced to less than seven parts per billion in modern deaerators, it must be reduced even further with chemical scavengers. Sodium sulfite is the most common scavenger used. Oxygen is removed by producing soluble sodium sulfate. The reaction is:



The reaction is slow at moderate temperatures. Catalysts such as copper and cobalt are sometimes added to the sulfite to enhance reaction in room temperature water. Catalyst feed is not necessary during normal unit operation because the trace metal content of makeup water is sufficient to catalyze the reaction. It is important to feed sodium sulfite at the earliest practical point in the system (preferably the deaerator storage section), to feed continuously, and to maintain sulfite residual according to levels recommended in paragraph 4-5. One disadvantage of sulfite treatment is that dissolved solids are added to the water. Oxygen control is as important in idle boilers as it is in operating boilers, and it is necessary to maintain proper sulfite residual while a boiler is shut down or in storage.

d. Dispersants. Unless the amount of material precipitated is very small, it is necessary to add dispersants to prevent the precipitated material from growing into aggregates. At high pressures, aggregates may become baked onto boiler tubes or form deposits that can lead to under-deposit corrosion.

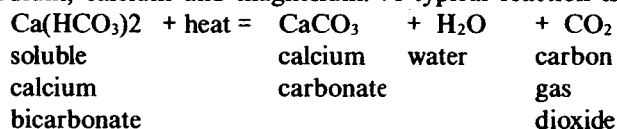
(1) **Quebracho Tannin.** Quebracho tannin is often used as a dispersant in Army boilers. After calcium and magnesium have been precipitated as sludge, tannin keeps the sludge from jelling into large solid masses so that it can be carried by the circulating water and removed by blowdown. This decreases sludge accumulation and scale formation. Tannin also has a corrosion control property in that it absorbs some of the dissolved oxygen and forms a protective film on steel. Finally, quebracho tannin provides smoother boiling with less carryover. Although other organic chemicals, such as extracts from other woods and seaweed have also been used as sludge conditioners, quebracho tannin is recommended for use in Army steam boilers operating under 400 psig.

(2) **Sulfonated Lignins.** Sulfonated lignins, which are by-products of the paper industry, are economical dispersants for phosphates and iron. They act by coating the particles to produce a clarified colloidal solution that can be controlled by continuous blowdown.

(3) **Synthetic Polymers.** During the past several years, a large number of polymer materials have been developed

which can effectively and economically replace the natural dispersants and coagulants. Polymers having properties of either cations or anions are available, as well as non-ionic materials. All of these materials may work effectively as dispersants, but may also be effective coagulant aids depending upon the concentration in which they are employed. Care must be exercised in the selection of polymers and the concentration used to assure optimum use of the materials and avoid coagulation-related problems.

e. Carbon Dioxide Control. Condensate line corrosion is one of the most severe corrosion problems faced by the Army. Carbon dioxide control, along with oxygen control, is important in preventing condensate return line corrosion. Carbon dioxide corrosion usually grooves and channels the bottom of the pipe. Frequently, it is most pronounced just beyond the traps of hot-water generators or radiators. The problem of internal corrosion of condensate return lines would not exist if carbon dioxide and oxygen could be kept out of the lines. Unfortunately, this is not possible. Carbon dioxide may enter the system as free carbon dioxide in the makeup water or it may be generated in the boiler by the decomposition of carbonates and bicarbonates of sodium, calcium and magnesium. A typical reaction is:



The carbon dioxide is discharged from the boiler with the steam. It then redissolves, either in pockets of condensate in the steam line or in the return condensate and forms carbonic acid. Carbon dioxide and oxygen become more corrosive when combined than they are individually. Both external treatment in the form of ion exchangers or degasifiers and internal treatment using neutralizing amines can be used to control carbon dioxide corrosion. Filming amines, such as octadecylamine, are not authorized. As stated in Army Regulation 420-49, steam treated with authorized neutralizing amines (morpholine and cyclohexylamine) must not be used directly for humidification or cooking purposes. A steam generating heating exchanger must be installed to provide amine-free steam at all locations where steam is used for direct contact cooking or humidification. Before amine treatment begins, all possible water and steam losses must be eliminated.

(1) **Reduction of Water Losses.** The amount of bicarbonate and carbon dioxide entering the boiler can be reduced by minimizing condensate losses, and therefore makeup rate. The makeup rate for a well-operated heating plant should not exceed ten percent of total boiler steam generation. Poorly operating steam traps waste steam and cause losses which must be replaced by makeup water. Piping leaks should be located and repaired immediately.

Makeup can also be reduced by careful control of blowdown. Reduction of water losses is also important because it allows recycling of the amine treatment chemicals, thus reducing chemical quantities and costs.

(2) **Morpholine and Cyclohexylamine.** These amines are alkaline chemicals which volatilize with the steam and combine with the carbon dioxide in the condensate to neutralize its acidity and protect against CO₂ corrosion. They are the only two amines presently authorized. They are usually used in 40 percent concentrations to minimize fire hazards. Distribution ratio (the ratio of concentration of the amine in steam to its concentration in water) is used as one means of selecting the proper material. At approximately 100 psia, a common distribution system pressure, ammonia has a distribution ratio of 10, cyclohexylamine about four and morpholine only about four-tenths. When steam first condenses, morpholine will be present in a larger concentration, due to its favorable distribution ratio, while at more distant points in the distribution system, cyclohexylamine will be available in large concentrations. These two chemicals are often used together to provide maximum protection. The proportion of the chemicals is determined by trial and error, starting with a mixture of 75 percent morpholine and 25 percent cyclohexylamine. Tests required are described in paragraph 4-15. If corrosion or a low pH is found toward the end of the distribution system, the percentage of cyclohexylamine is increased. If corrosion or low pH is found toward the beginning of the distribution system, the percentage of morpholine is increased. If the corrosion is found in the middle of the distribution system, additional quantities of both morpholine and cyclohexylamine may be required. Feeding to an operating boiler must be continuous and at a rate sufficient to maintain a minimum pH of 7.5 to 8.0 at all points in the distribution system. Testing for condensate corrosion is discussed in paragraphs 4-14 and 4-15.

f. Low Temperature Water Treatment. For low temperature water systems operating at 250° F or less, there are a number of treatments which can be employed. In fact, treatments which are commonly used in cooling water systems can provide excellent corrosion control in LTW systems as well. A treatment which will generally provide good corrosion control is one employing borax and nitrite. This treatment is normally applied with levels of 1,500 to 2,500 ppm (or as recommended by the chemical supplier) as formulated compound maintained in the loop to be treated. Borax-nitrite treatment is easy to control in a water system which has little leakage and low makeup. Periodic analyses should be performed. Weekly tests are suggested with the nitrite residual being measured. The chemical concentration should be readjusted to maintain residuals in the range of 1,500-2,500 ppm. Nitrite reducing

bacteria can periodically infest a system and rapidly deplete the nitrite in the water. Depending on the operating temperature of the system, these bacteria may or may not be sterilized. If they are not sterilized, rapid depletion of nitrite will occur and the solution will not adequately protect the system from corrosion. Weekly tests will indicate this condition. Copper corrosion inhibitors are frequently added with the borax-nitrite when copper alloy heat exchangers are included in the distribution system.

4-8. BLOWDOWN

The following equipment is used to provide an economical, continuous blowdown system on steam boilers.

a. Flash Tank with Heat Exchanger System. When blowdown water leaves the boiler, whether from a bottom purge or a continuous surface blowoff, it is a hot, pressurized liquid. The sudden reduction to atmospheric pressure causes some of this liquid to flash into steam. For safety reasons, this change of phase must occur in a specially designed vessel called a flash tank. The steam from the flash tank can then be passed through the feedwater heater. The hot water flowing from the flash tank usually contains enough heat to justify passing it through a heat exchanger to preheat makeup water. Reference figure 4-18. This equipment is economical to install on any size boiler or group of boilers. For boilers operating below 15 psig, and some boilers operating at higher pressures and makeup water rates, the heat exchanger alone is sufficient to cool the blowdown water to the point at which it can be discharged into the sewer.

b. Conductivity Meter and Automatic Controls. Blowdown can be automatically controlled through the use of a conductivity sensor. The conductivity sensor works on the principle that ionizable solids in the boiler water cause the solution to conduct electricity. The higher the concentration of ionizable salts present, the greater will be the conductance of the sample. The controller opens and closes the blowdown valve as required to maintain the proper conductivity. Figure 4-19 diagrams the automatic continuous blowdown controls. This equipment is economical to install on many boilers, especially where chemistry and dissolved solids are difficult to control. A conductivity meter should preferably have a minimum range of 0 to 5,000 micromhos. This will allow analysis of either boiler water or condensate. Automatic or manual temperature compensation should also be included. The meter shown on Figure 4-20 is available from USAEHSC on "Order Blank - For Boiler Water Testing Equipment," Form No. 278. This meter has a five-position switch which allows for five ranges, 0 to .5, 0 to 5, 0 to 50, 0 to 500, and 0 to 5,000 micromhos. Conductivity meters with scales showing total dissolved solids (TDS) should not be used

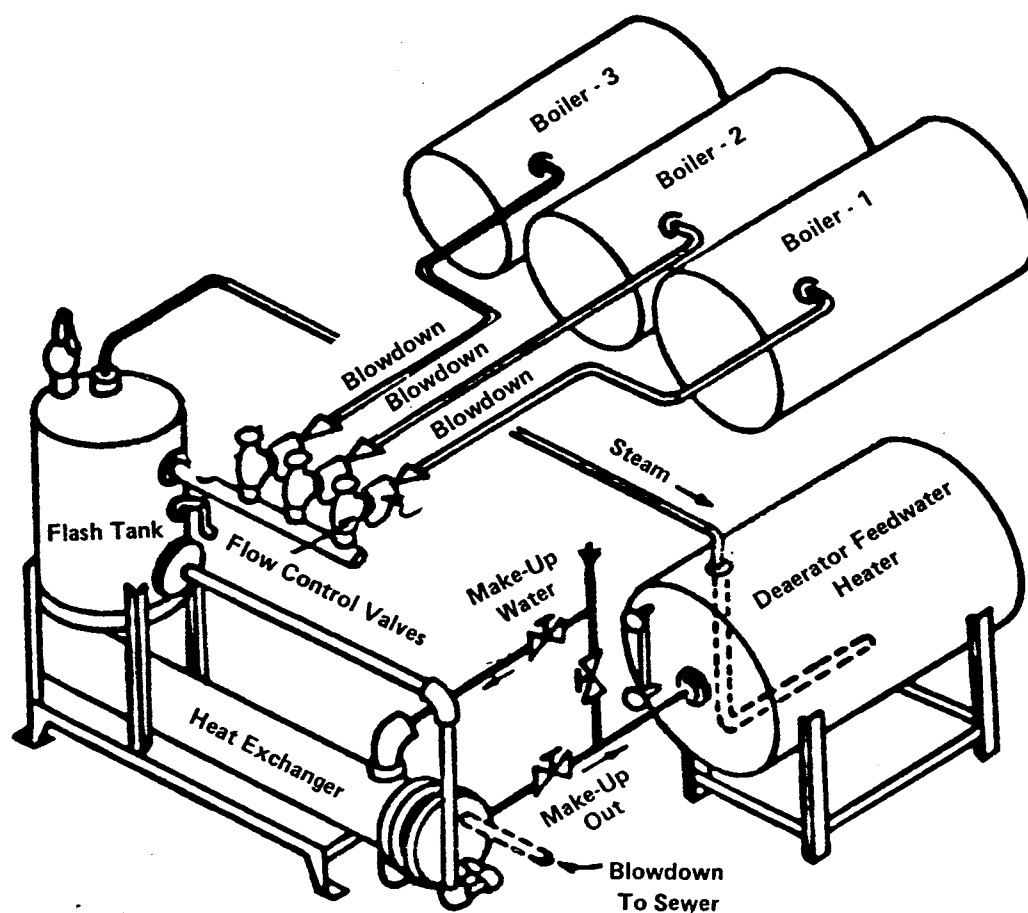


FIGURE 4-18. BLOWDOWN SYSTEM WITH FLASH TANK AND HEAT EXCHANGER

Since the conversion factor from micromhos to TDS is unknown and must be adjusted for different boiler waters

and condensate. Reference appendix B, paragraph B02e for conductivity test procedure for boiler water.

SECTION III. OPERATION

4-9. BOILER WATER TREATMENT OPERATING LOG

An example of the monthly Repair and Utilities Operating Log (Boiler Water Treatment), DA Form 4367, is shown in figure 4-21. Regulation requires this log to be maintained in plants operating above 15 psig steam or 300 psig water with an output capacity above 3.5 MBtu/hr or 100 horsepower. This log provides a record of boiler, makeup and condensate water treatment and test results. The data obtained from this log makes an accurate analysis of plant operation possible. Entries are made in columns. An explanation on the use of each column is on the back of the form. One log should be maintained for each boiler and one for plant makeup water data. Columns 19 and 20 may be used to record condensate conductivity and hardness. If a boiler is secured in a wet condition, causticity and sodium sulfite residual should be indicated in the remarks block. If the boiler is secured dry, the frequency of desiccant inspection should be indicated. Organized operating logs should also be maintained for low pressure boilers and for HTW, MTW, and LTW systems. The logs should contain the following information: results of all chemical tests, dates tests performed, amounts of chemicals added, dates chemicals added, and amount and time blowdown performed. Periods of boiler layup and downtime maintenance should also be recorded.

4-10. PROCUREMENT OF STANDARD AND SPECIAL TREATMENT CHEMICALS

Prescribed chemicals for boiler plant water conditioning may be procured as listed below.

a. Caustic Soda. Specify: "Caustic soda for boiler feedwater treatment; to contain not less than 76 percent sodium oxide (Na_2O) and be in flake form." As it absorbs moisture readily and becomes sticky, specify shipment of the chemical in 100-pound steel drums. This chemical may be procured from commercial sources.

b. Sodium Phosphate. Sodium phosphates may be specified with reference to table 4-4. Example: For sodium metaphosphate specify "Compound, boiler feed water, Type II sodium phosphate, glassy, 67 percent P_2O_5 ." The chemical is shipped in 100-pound bags and may be procured from the Federal Supply Schedule.

c. Quebracho Tannin. Specify: "Quebracho tannin, solid, for boiler feedwater conditioning; suitably processed to obtain easy solubility; shall be of the following composition:

shall contain not less than 65 percent quebracho tannin, not more than 17 percent non-tannin, nor more than 1 percent insoluble, and not more than 20 percent water; packed in 100-pound bags." This chemical may also be procured from the Federal Supply Schedule.

d. Sodium Sulfite. Specify: "Sodium sulfite (Na_2SO_3), anhydrous, for boiler feedwater treatment; to contain at least 90 percent Na_2SO_3 , the remainder to be primarily sodium sulfate (Na_2SO_4), sodium carbonate (Na_2CO_3), with less than 1 percent moisture; a 10 percent solution to be alkaline to phenolphthalein."

e. Antifoams. For antifoam or other special water treatment chemicals, consult the operating agency commander for the proper chemical to use and the correct method of application.

f. Rock Salt. A good grade of rock salt is preferable to granulated salt for regeneration purposes. Rock salt does not cake, as do many grades of granulated salt, and it is equally effective as a regenerating agent. The salt should contain not less than 98 percent sodium chloride with a minimum of calcium and magnesium salts, contain less than 1.5 percent of dirt or other insoluble matter, and have a grain size within the 10 to 50 mesh range.

g. Morpholine. Specify "Morpholine ($\text{C}_4\text{H}_9\text{NO}$), boiler feedwater compound, used to control carbon dioxide corrosion in steam condensate lines; 40 percent morpholine content; all drums to bear adequate caution labels to protect against fire, poison, and caustic burn hazards; packed in 480 pound drums (55 gallon drums)." Available from the Federal Supply Schedule.

h. Cyclohexylamine. Specify "Cyclohexylamine ($\text{C}_6\text{H}_{11}\text{NH}_2$) boiler feedwater compound, used to control carbon dioxide corrosion in steam condensate lines; 40 percent cyclohexylamine content; all drums to bear adequate caution labels to protect against fire, poison, and caustic burn hazards; packed in 420 pound drums (55 gallon drums) or packed in 40 pound drums (5 gallon drums)." Available from the Federal Supply Schedule.

i. Proprietary Compounds. As a general policy, use of premixed chemical compounds is not authorized. Such compounds, if proportioned correctly for a specific water, generally cannot be used advantageously without change for water of a different analysis. As the boiler compound is a fixed mixture of chemicals, there is no way to adjust the dosages of individual chemicals for maintaining the desired concentrations of each in the boiler. Exceptions